FACULTY OF INFORMATION TECHNOLOGY AND ELECTRICAL ENGINEERING

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ENABLING ENVIRONMENTAL FINGERPRINTING WITH AN NFC-POWERED SENSOR BOARD

Master's Thesis
Degree Programme in Computer Science and Engineering
May 2018

Opoku Asare K. (2018) Enabling environmental fingerprinting with an NFC-powered sensor board. University of Oulu, Degree Programme in Computer Science and Engineering. Master's Thesis, 55 p.

ABSTRACT

In recent times, people have become concerned about their environmental conditions, amid deteriorating global statistics on bad air quality, global warming and UV light exposure. Conventional technologies for reading environmental conditions are expensive, bulky and situated, yet, people are mobile and need portable tools to be aware of their immediate environmental conditions on demand. Smartphones are now widely used, endowed with sensors and wireless communication technologies such as Bluetooth, and Near Field Communication (NFC) for external sensor connectivity, making smartphones a viable tool for fingerprinting the environment. This thesis outlines the design, evaluation and implementation of a mobile-enabled system for environmental data collection using a portable NFC powered sensor board. The name of the system developed in this thesis is the S3 system.

The S3 system is a two-tier system which consists of S3 Android application and an online dashboard with a data repository. The S3 Android application is used for collecting and visualising environmental data; temperature, humidity, UV, ambient light, with a smartphone and a credit card-size NFC powered sensor board. The sensor data is then periodically synced to the online data repository. Additional features of the S3 application include automated feedback sampling, introductory tutorial, and user preference settings. The thesis further details the design and implementation process with scenarios, use cases, paper sketches, expert review of sketches, interface mockups, evaluation of prototype with a user study, quantitative and qualitative analysis of user study data, and finally the implementation of the S3 application. The thesis also presents a test run to demonstrate the capabilities of the S3 system as a mobile-enabled solution for crowdsourced environmental fingerprint datasets.

To the end user, the work in this thesis provides the S3 application and the NFC powered sensor card as a portable tool for personalised environmental fingerprinting. On the other hand, the intervention in this thesis will have an impact on research since the crowdsourced environmental fingerprint datasets can be valuable datasets for research. As a TEKES project, the solution also provides a proof of concept for further improvement and deployment into the commercial software market.

Keywords: environment sensing with smartphones, portable NFC-powered sensors, environmental fingerprinting

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FOREWORD

This thesis is funded by the Finnish Funding Agency for Technology and Innovation (TEKES) under the S3-Simple Smart Sensor project.

For their tutoring, guidance, assistance and motivation, I thank, particularly my supervisors Dr. Denzil Ferreira, Dr. Simo Hosio, and my colleagues; Simon Klakegg, Aku Visuri of the Center of Ubiquitous Computing (UBICOMP). I also thank Dr. Christian Schuss and Tore Leikanger of the Circuits and Systems (CAS) research group for their collaboration on the S3 project.

To Professor Timo Ojala, the Director of UBICOMP, I say a big thank you for giving me the opportunity to study and work in Finland.

Lastly, to my family in Ghana, I express my gratitude for your support in diverse ways on the journey thus far.

Oulu, 20, April 2017

Kennedy Opoku Asare

LIST OF ABBREVIATIONS

API	Application Programming Interface
BLE	Bluetooth Low Energy
BR	Basic Rate
CAS	Circuits and Systems research group, University of Oulu
CSV	Comma Separated Values
EDR	Enhanced Data Rate (EDR)
EF	Environmental Fingerprinting
GPS	Global Positioning System
HTTPS	Hypertext Transfer Protocol Secure
JSON	JavaScript Object Notation
NFC	Near Field Communications
S3	Simple Smart Sensor
UBICOMP	Center for Ubiquitous Computing, University of Oulu
UI	User Interface
UUID	Universally Unique Identifier
UV	Ultraviolet
Wi-Fi	Wireless Fidelity

1. INTRODUCTION

In recent times, the need to be aware of environmental conditions such as temperature, humidity, Ultraviolet (UV) index, and air quality is on the rise. People have become concerned about these environmental conditions, amid deteriorating global statistics on bad air quality, global warming and UV light exposure. Conventional technologies for reading environmental conditions are expensive, bulky and situated [36], and do not serve people's needs. In other words, people are mobile and need portable tools in order to be aware of their immediate environmental conditions on demand.

Smartphones are now widely used [37,38] and endowed with embedded sensors [31]. However, most smartphones lack the sensors needed to collect environmental data such as UV, temperature, air quality and water quality. Nevertheless, smartphones have the technology to connect external sensors via wireless communication channels such as Bluetooth, and Near Field Communication (NFC), which makes it possible to use smartphones to collect data to know more about the environment.

The aim of this thesis is to contribute to research in the area of Environmental Fingerprinting by developing a mobile-enabled client-server architecture for crowdsourced environmental fingerprint datasets. Environmental Fingerprinting is herein defined as; the process by which an entity becomes aware of its environmental context via sensing data in its surroundings. Herewith, the environmental context of the entity could be air pressure, temperature, humidity, air quality, or ambient light.

This thesis is done as part of the Finnish Funding Agency for Technology and Innovation (TEKES) funded S3-Simple Smart Sensor project, under the collaborative effort of researchers from Circuits and Systems (CAS) research group and Center for Ubiquitous Computing, at the University of Oulu.

To the end user, the solution provided in this thesis serves as a portable tool for personalised environment fingerprinting. On the other hand, the intervention in this thesis will impact on research since the crowdsourced environmental fingerprint datasets can valuable datasets for research. As a TEKES project, the solution also provides a proof of concept and a solid bedrock for further improvement and deployment into the commercial software market.

The solution in this thesis will be evaluated by a user study of the designed solution, and a developed android based smartphone application, that senses, and visualises data from an NFC powered sensor board, and in addition, shares the data to an online data repository.

2. RELATED WORK

The following sections surveys earlier research and existing solutions for sensing data from the environment. It also discusses embedded and external smartphone sensors, Bluetooth and NFC wireless connectivity, as well as the opportunities they avail in collecting data about the environment.

2.1. Smartphone Sensors

Smartphone sensors are generally categorised into motion sensors, position sensors and environment sensors [31]. Motion sensors, for example, accelerometer, and gyroscope are used to measure physical angular or linear movement in an x, y, z plane. Activity recognition such as signification motion, step count, linear acceleration, running, waking, relies on motion sensors.

Similarly, positions sensors, for example, magnetometer, and proximity sensors are used to measure the physical position a device, in an x, y, z plane, or the earth's geomagnetic plane. Measuring the orientation of a smartphone, how close the smartphone is to a reference object, is made possible with the presence of position sensors on the smartphone.

Likewise, environment sensors, for instance, ambient light, ambient air pressure, ambient humidity, and temperature, are used to fingerprint the environment. Smartphones use the ambient light sensor to measure illuminance in the environment to automatically regulate the brightness of their screen.

2.2. Smartphone Connectivity with External Sensors

Smartphones are equipped with the technology that allows connectivity to external sensors. Short-range wireless radio technologies such as Bluetooth and NFC technology are used in connecting smartphones with external sensors.

Much research has been done using smartphone connectivity to phone external sensors via Bluetooth and NFC. Rahman *et al.* [20] demonstrated smartphone connectivity with external sensors via Bluetooth wireless technology. Their solution enabled the detection of wet diapers, by sending Bluetooth signals to a smartphone after detecting a drop in resistance between the terminals of an electronic conductor. Similarly, Strömmer *et al.* [7], prototyped a temperature sensing application by using an NFC enabled mobile device, and a prototype matchbox-sized sensor device comprising a rechargeable Li-Ion battery, a programmed microcontroller, a data logging memory, and a temperature sensor, among others. Likewise, Stetter *et al.* [18] also developed an air quality sensing applications that allow NFC enabled phones to sense air quality data from a business card sized electrochemical sensor card.

The following sections presents a detailed description and comparison of Bluetooth and NFC technologies.

2.2.1. Near Field Communication Technology

Near Field Communication [10] is a short-range wireless point-to-point connectivity technology, jointly developed by Philips and Sony in 2002. Operating with a 13.5 MHz frequency and 0.106 - 0.424 Mbps data transfer rate [10], NFC enables a low powered, contactless communication in a fraction of a second between a smartphone and another device, both within a range of 4 - 10 cm of each other.

NFC systems communicate in passive or active modes [8]. During communication, one device is assigned as the initiator and the other as the target. In active mode, both initiator and target devices actively generate their own radio frequencies for the data transmission. In passive mode however, only the initiator device generates the radio frequency needed in data transmission and powering the target device using inductive coupling. Passive mode communications save power on the target device and allow communication between battery-powered smartphone initiator and batteryless external sensors.

Since the inception of NFC technology in March 2004 [10], much research has focused on building ultra-low power sensors with NFC [7], the application of NFC in mobile applications for health monitoring[13,14], access control and authentication systems[11,19], and educational technologies [15,16,17]. In the smartphone application industry also, NFC technology has been used in smart payment and commerce applications such as, Nordea Pay[1], Waltti[2], and Apple Pay[3].

2.2.2. Bluetooth Wireless Technology

Bluetooth is a short-range, low power wireless communication technology for Personal Area Networks developed by the Bluetooth Special Interest group [22]. Operating in the 2.4 GHz frequency band, Bluetooth technology enables point-to-point, broadcast, and mesh wireless communication between smartphones and other devices and sensors within a range of 10 - 100 meters.

The version 4.0 of Bluetooth provides two radio technologies; Basic rate (BR)/Enhanced Data Rate (EDR) also known as BR/EDR, and Bluetooth Low Energy (BLE). BLE radio technology supports low powered data transfer rate of 0.125 - 2.0 Mbps between devices where data transfer is done in small packets at a time, for

[1] https://play.google.com/store/apps/details?id=fi.nordea.mep.npay

[2] http://waltti.fi/walttikortti/?lang=en

[3] https://www.apple.com/apple-pay/

instance, smartphone connectivity to fitness trackers and heart rate monitors like Fitbit[4], health monitoring systems [23] and other sensors. BR/EDR radio technology supports 1 - 3 Mbps data transfer rate, and suitable for communications between devices (one-to-one) that require constant connectivity and data streaming, for instance, the one-to-one connection of a smartphone to a wireless speaker or headsets. Communication using BR/EDR consumes a relatively higher power than BLE.

Bluetooth technology has been used as the wireless connectivity between smartphones and other devices in indoor positioning systems [25,26] and medical devices [23,24]. Applications such as Science Journal from Google [2], Simplelink SensorTag from Texas Instruments [3] has the feature for sensing data from external sensors over a Bluetooth connectivity.

2.2.3. NFC versus Bluetooth

Both NFC and Bluetooth are short-range wireless technologies that enable connectivity of smartphones to external sensors. Bluetooth has a longer range of connectivity than NFC, however, NFC takes lesser time and often instant, in pairing up or connecting devices together, while Bluetooth may take much more time in discovering devices before connecting to them. In order to capitalise on the strength of both technologies, NFC forum [10] and the Bluetooth Special Interest Group [22] has released a reference document [27] for implementing Bluetooth device pairing using NFC. Table 1 shows a comparison of NFC and Bluetooth.

The major drawback for Bluetooth connectivity, in general, is high consumption of device battery life. Users of smartphones cherish their battery life [4,5,6] and go at any length including turning off Bluetooth connectivity to conserve battery. The advent of BLE mitigates this concern, however, BR/EDR still consumes considerable amount smartphone battery.

NFC on the other hand, consumes less battery power as compared to Bluetooth (BR/EDR, BLE). In NFC passive mode, only one device, for instance, the smartphone (the initiator) needs to have a battery or a power source, and the other device can be batteryless. This is not the case for Bluetooth connectivity where all connected devices must have a battery or power source.

[4] https://www.fitbit.com/fi/how-to

Table 1. Comparison between NFC and Bluetooth [8,10,22]

Parameter	NFC	Bluetooth	
		BR/EDR	BLE
Range per two connected devices	4 - 10 cm	10 - 100 m	10 - 100 m
Data transfer rate	0.106 - 0.424 Mbps	0.125 - 2.0 Mbps	1 - 3 Mbps
Frequency	13.56 MHz	2.4 GHz	2.4 GHz
Network topology	Point-to-point	Point-to-point	Point-to-point, mesh, broadcast
Power consumption	Lower	High	Low
Number of devices that needs a battery or power source	At least one device	All devices	All devices

2.3. Environmental Fingerprinting

Smartphones have become a relatively cheap, and ubiquitous tool for large-scale environmental fingerprinting and monitoring as compared to conventional industrial scale and urban sensor installations, for example, Opensense[5], which monitors urban air quality using data sensed from environment sensors deployed atop trams, buses and cars. Consequently, Aitkenhead *et al.* [32] reviewed a number of existing solutions that collect, process and reports environmental data with smartphones and external sensors, for instance, sensordrone[6].

The following sections set focus on environmental fingerprinting using smartphones and environment sensors, for example, Air quality, Ambient Light, Temperature and UV sensors.

[5] http://opensense.epfl.ch/wiki/index.php/OpenSense_2.html

[6] https://www.kickstarter.com/projects/453951341/sensordrone-the-6th-sense-of-your-smartphoneand-be

2.3.1. Air Quality Sensing

Statistics available from World Health Organisation (WHO) shows that 92% of the world's population live in environments of bad air quality[7], and about 3 million deaths in a year, are linked with bad air quality. These facts and many others have nowadays made people more curious about the air quality in their surroundings.

To fingerprint air quality of urban places and to provide a personalised air quality sensing system for users, Zhang *et al.* [33] developed a sensing system which was evaluated in 10 metro stations in London. In their research, they use an optical sensor device that measures the temperature, and the concentration of dust in the surrounding air. The sensor then transmits the data via BLE connectivity to a smartphone. The smartphone annotates the data with Global Positioning System (GPS) coordinates and time of day. The data collected was analysed with a machine learning algorithm, to predict the air quality of the metro station, and to also calculate and visualise health impact index, and air pollution maps on the smartphone.

Likewise, Wu *et al.* [34] developed an air quality sensing system whose measurements showed a strong correlation with Environmental Protection Agency data in California. Their system dubbed c-Air used a smartphone camera to scan the environment to generate microscopic images, tag the images with GPS data, and transmit them to an online server for processing. At the server side, the images are processed with image processing and machine learning algorithms. The generated results are then visualised on the smartphone.

Stetter *et al.* [18] also developed a portable air quality sensing system with a business card sized sensor card with which a user senses data on demand using a smartphone application, via an NFC communication.

2.3.2. Ultraviolet Index Sensing

UV index measures the level of risk of harm from unprotected sun exposure. High UV index means there is a need for protection against skin and eye damage.

To fingerprint UV index for people to be more aware of their UV exposure, Fahrni *et al.* [35] in their research, developed Sundroid, a smartphone application that senses UV index in real time, from a body-worn sensor, over a Bluetooth connection. The UV index data is tagged with geolocation and timestamp and visualised on the smartphone. Sundroid also notifies users in high UV index environment.

A similar solution is described in Cheuk *et al.* [39]. The solution in their research provides a personalised UV index tracking system, with a wearable UV sensor and a smartphone. The smartphone senses data from the UV sensor using Bluetooth connectivity. The smartphone application then presents personalised

[7] http://www.who.int/mediacentre/news/releases/2016/air-pollution-estimates/en/

insights to the user in addition to the UV index, for example, burn time and cumulative dosage of UV.

2.3.3. Temperature and Humidity Sensing

On temperature and humidity sensing with smartphones, Aram *et al.* [30] developed a Bluetooth based sensing system comprising of an electronic circuit board, powered with a 1000mAh lithium battery, and aBluSen, an Android based mobile phone application. To evaluate the accuracy of the sensing system, the sensor was placed in a climatic chamber in a laboratory, where the temperature in the chamber was varied during a three-hour experiment. The results demonstrated that the temperature recorded by the sensing system accurately matched the temperature variation imposed by the climatic chamber.

2.4. Mobile Instrumentation Applications and Frameworks

Not only in research but also from the software industry, a number of software solutions exist that are used to sense data from smartphone embedded sensors, and external sensors. Some examples of such solutions related to the work in this thesis are Science Journal [2], ResearchKit[8], Simplelink Sensortag [3], and Beurer Sleep Expert [21].

Science Journal [2] is a mobile instrumentation application from Google that essentially turns any smartphone into a sensor data collection tool, for research and education. Science Journal application supports the Android and iOS operating systems and enables connectivity to external sensors via Bluetooth connectivity, visualises the data, and also allows the export of the sensor data to CSV. Science Journal also has an open source Application Programming Interface (API) for developers to integrate its functionalities into their applications.

Simplelink Sensortag [3] is another mobile sensing application from Texas Instruments. Similar to Science Journal, Simplelink SensorTag supports both Android and iOS and allows for sensing data from external sensors via BLE. Simplelink Sensortag application only connects to sensors commercially manufactured by Texas Instruments. It also saves the sensed data to the cloud rather than only locally on the smartphone in comparison to Science Journal application. Simplelink Sensortag also visualizes the sensor data in charts.

ResearchKit from Apple, is also another open source framework that allows developers and researchers to create applications for medical research on iOS devices, mainly by sensing data from the device embedded sensors.

[8] http://researchkit.org/

Beurer Sleep Expert [21], ships as an iOS and Android application for measuring and improving sleep. The application senses data from a custom-made Beurer sleep sensor, via BLE connectivity to the smartphone that runs the application. The application analyses the sensor data and presents the interpretation using visualisations.

2.5. Contribution

This work contributes to research on smartphone environment data sensing from external zero power portable wireless sensors with NFC technology. In making this contribution, this thesis uses a design science research approach to create a solution which is a mobile-enabled client-server architecture for crowdsourced environmental fingerprint datasets.

This thesis designs, evaluates and implements an Android based mobile application that senses data from a credit card-sized NFC powered sensor board with multiple environment sensors. The evaluation is done with a user study that collects qualitative and qualitative feedback to inform the application implementation. The implemented application visualises the sensor data and syncs the data to an online data repository.

The work in this thesis provides a cost-effective environmental fingerprinting tool for research and personal use. The solution will also create a proof of concept for further development and deployment into the commercial software industry.

3. SYSTEM DESIGN AND IMPLEMENTATION

The designed system in this thesis is named Simple Smart Sensor (S3) system and follows a two-tier client-server architecture. Figure 1, below, show a high level architecture of the S3 system. The client subsystem consists of an Android mobile application, called S3 application which runs on a smartphone with NFC sensing capabilities. The S3 application collects data from an NFC powered sensor board with multiple sensors named SensorCard. The S3 application persists the sensor data into an SQLite database stored locally on the smartphone. An AWARE Data Sync Service running in the background periodically syncs the sensor data over Hypertext Transfer Protocol Secure (HTTPS) connection in JavaScript Object Notation (JSON) data format to the Server. The server hosted in the cloud is an AWARE dashboard persisting to a MySQL database.

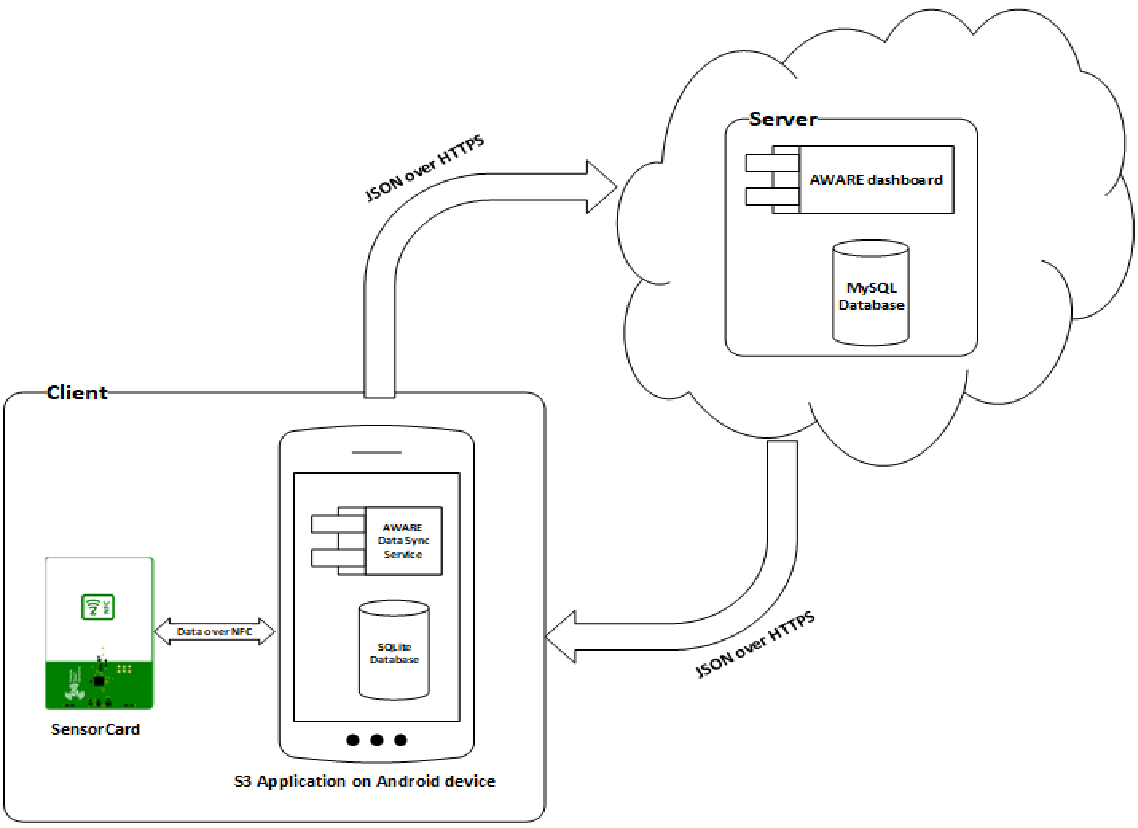


Figure 1. High level overview architecture of the designed system.

The SensorCard[9] is an invention of the Circuit and Systems (CAS) research group of the University of Oulu, Finland. The SensorCard a portable NFC powered sensor in the size of a credit card, as seen from Figure 2. The SensorCard can easily fit into the pockets or flip cover of user’s mobile phones. Since the SenserCard works

[9] http://slentre.net/s3/

with NFC communication, it does not require a battery or power source to operate. The smartphone at the point of reading the data provides all the power the SensorCard needs to sense and transmit data. The sensors currently available on the SensorCard are temperature, humidity, ambient light, and UV index, and in future water quality and air quality sensors would be added.

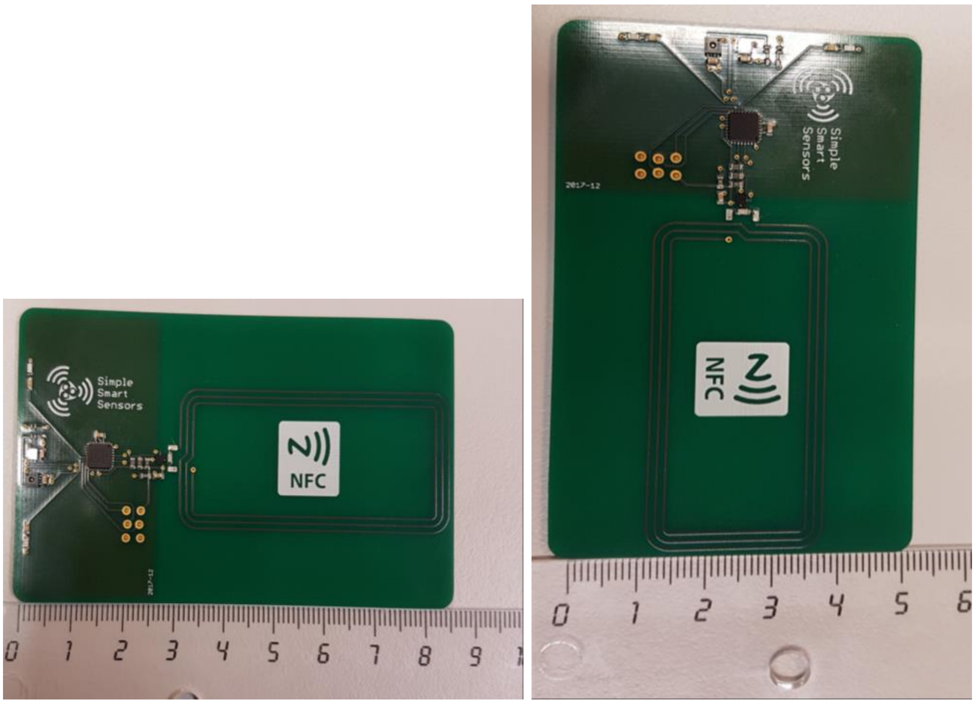


Figure 2. Pictures of SensorCard.

The following chapters dive into the details of design and implementation of the various components of the S3 system.

3.1. S3 Application Design and Implementation

The design and implementation process of the S3 application followed a hybrid of Waterfall and Interaction design software development models. This hybrid process has four stages, executed successively. Figure 3 shows the stages in the design and implementation process of the S3 application. These stages are the Requirements gathering stage, Prototyping stage, Evaluation stage, and finally the Implementation stage.

At the Requirements gathering stage, the application was conceptualised with scenarios and use cases after a literature review. The scenarios and use cases were designed with target user groups; travellers, environmentalists, persons with health conditions, researchers, the general public, in mind.

Next to the Requirements gathering stage is the Prototyping stage. At this stage, the scenarios and use cases were translated into user interface (UI) sketches using pencil and paper. The UI sketches were then converted into UI mockups after an expert review.

The next stage is the Evaluation stage where a user study was conducted with 30 participants to test and evaluate the UI mockups. The data collected during the user study was then analysed using quantitative and qualitative methods. The findings from user study data analysis informed the implementation of the S3 Android application.

The final stage is the Development stage. At this stage, several iterations of coding and testing of the application were done until the desired final version.

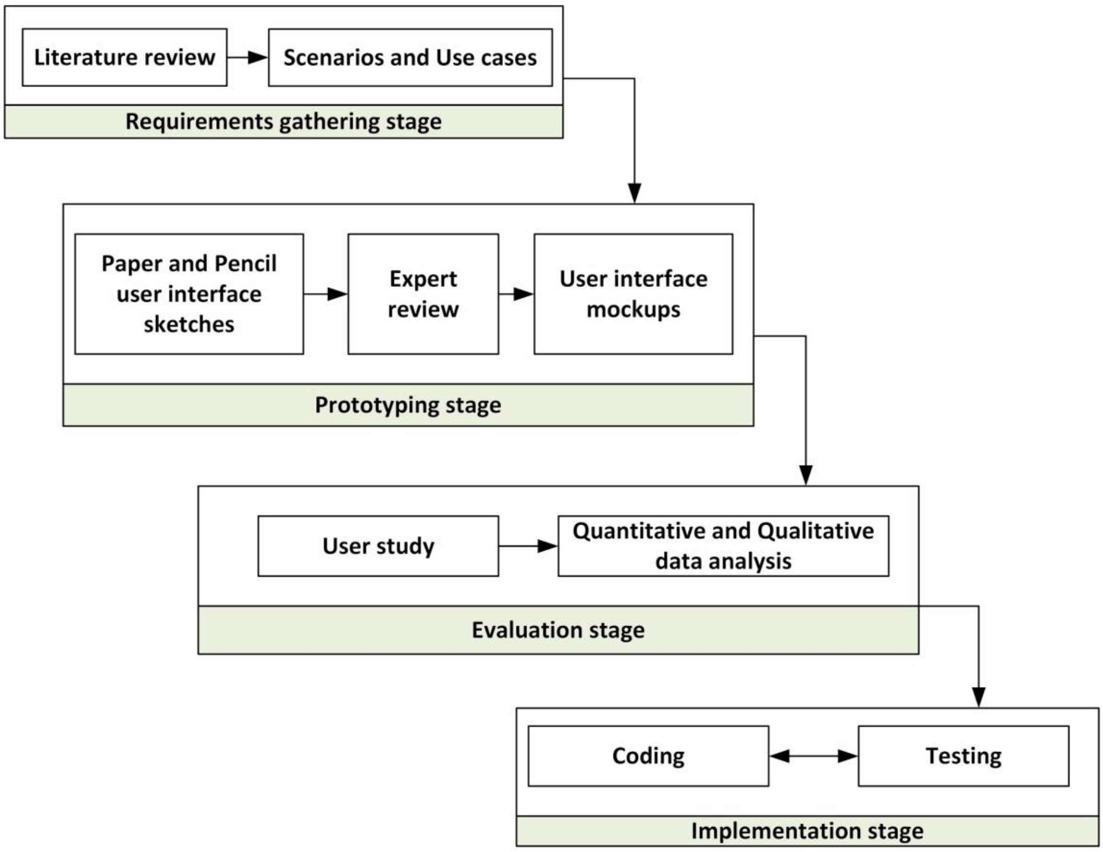


Figure 3. Design and Implementation process of S3 application.

3.1.1. Scenarios

The following scenarios illustrates how three users Doe, John and Juha would use the proposed S3 application to achieve their goals. This process allows us to iteratively assess the application's capabilities against different user needs.

Doe is a 33-year-old business executive and travels frequently across continents and nations for business and holidays. He does not want to ruin his travels with diarrhoea, sunburn, and bad air quality. He needs a means to check the water quality of the water he drinks on travels and whether it is ok to swim in the lake he finds at the holiday place, and whether it is okay to go outdoors and have some fun, without worrying about sunburns. Doe already owns an Android smartphone. He acquires the SensorCard, downloads and installs the S3 Android application. He can now measure the water quality of his drinking water and bath water to know if it is safe to drink the water or bath with it. Anytime he wants to stay outdoors, he reads the UV index with the SensorCard and S3 application on his smartphone. The readings help him to know whether or not to worry about sunburns and wear protective sunglasses and clothes. He is also able to check the air quality, temperature, humidity, and ambient light of his hotel room. Doe is excited to use the SensorCard and the S3 application, because of its utility and the solutions it provides to his needs.

John is a 56 years old industrial worker and asthmatic patient. He is aware that the air quality, temperature and humidity of the environment he is situated in influences his asthmatic condition and how often he would have to use the inhaler. He needs information and actionable recommendations relevant to his health situation, and reminders to check the air quality, humidity and temperature of his environment. He downloads and installs the S3 application, acquire a SensorCard, and configure the application to suit his profile. At the moment, he is comfortable the solution provided him by the application and is now able to avoid environments with poor air quality and low humidity. John has now seen improvement in the number of times he needs to use an inhaler. He can also visualise the historical measurements of temperature, humidity and air quality of some bookmarked locations.

Juha is a 30 year old environmentalist and postdoctoral researcher, at a university. In his research, he is aware that it is possible to collect localised UV index, ambient light, temperature, humidity, air quality, and combine it with local weather data and research into how these conditions, influences people's work output in the university environment. He has clear budget constraints and wants to use a crowdsourcing approach. There are 40 students willing to volunteer for his research. He acquires SensorCards, and with any android based smartphone with NFC capabilities, with no requirement for onboard sensors, Juha directs the students to install the S3 application. Twice weekly for a period of six months, he receives high quality localised UV index, temperature, ambient light, air quality data from students. He is able to do quality data collection within his budgetary constraints and he is happy to use the S3 System as a tool for his research.

3.1.2. Use Cases

Following the scenarios, the possible set of actions the users could perform with the S3 application were identified, thus setting out the use cases. The use cases were associated with sensing data from the SensorCard, viewing sensor data history visualisation, changing settings of the S3 application and viewing help. Figure 4 shows a use case diagram of the S3 application.

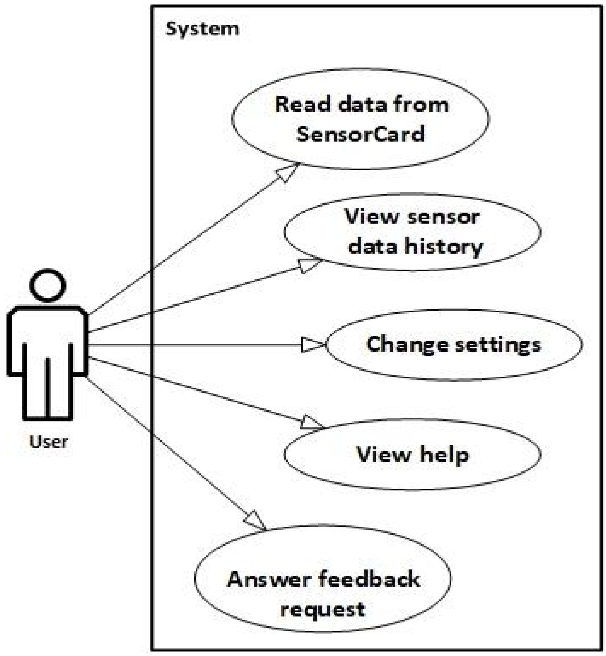


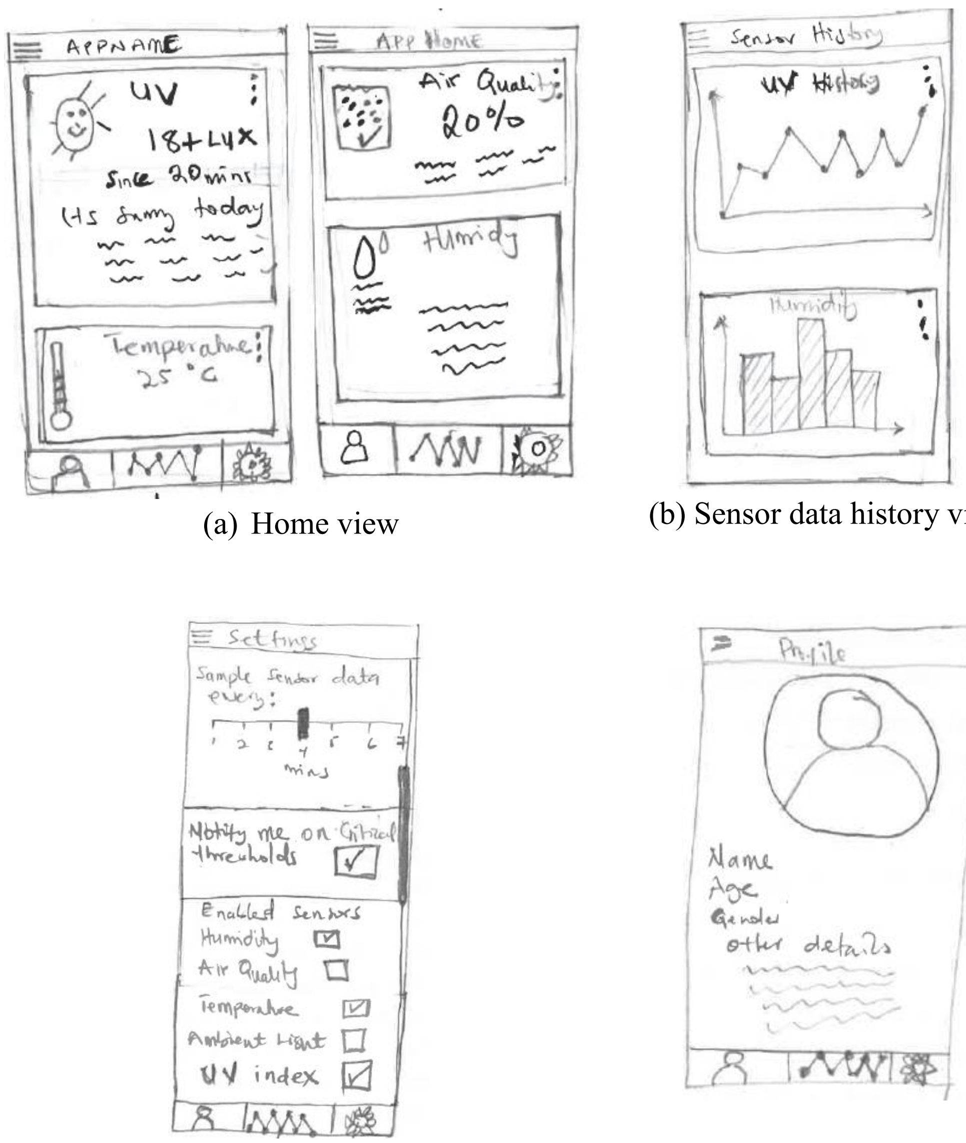
Figure 4. Use case diagram of the S3 application.

3.1.3. User Interface Design

Based on the scenarios and use cases, a UI sketch of the S3 application was made with a pencil and paper. The sketches were then subjected to expert evaluation together with researchers from UBICOMP and CAS. The feedback from the expert evaluation was factored into the design interface mockups.

3.1.3.1. User Interface Sketches

Interface sketches were created for home, sensor data visualisation, user profile and settings views. Figure 5 a to d, shows the UI sketches.



(a) Home view

(b) Sensor data history view

(c) Settings view

(d) User profile view

Figure 5. User interface sketches based on scenarios.

Note that in Figure 5, above, the menus are located at the bottom of the interfaces. Also from (c), Settings view, at this UI sketches stage, allowed users to vary the settings for data sensing rate, application notification at critical thresholds, and also enable or disable some sensors. The sketches also showed a user profile where users would provide to the application their name, age, gender etc.

3.1.3.2. Expert Evaluation of User Interface Sketches

During the expert evaluation of the UI sketches, each sketch was reviewed with due cognisance to the scenarios and use cases, usability, and the limitations of the technology. The following paragraphs detail the consensus resulting from the expert evaluation.

First, considering the implementation of NFC in Android smartphones, the NFC is turned off when the smartphone's screen goes off. Moreover, the SensorCard must be close to the NFC antenna of the smartphone, which is usually located at the centre or sometimes close to the top of the smartphone's backside. In view of this, the user has to actively and optimally place the SensorCard and the smartphone to take measurements. Consequently, the "notify me on critical threshold" idea on the settings view of the UI sketches (Figure 5 c) is not feasible. In other words, the idea cannot be implemented since it would mean that the smartphone has to persistently connect to the SensorCard and continually sense data at a defined rate.

Second, from a user's perspective, the idea of choosing the sampling rate or how often data is collected from the SensorCard adds a level of complexity to the application, hence "sample sensor data every" on the settings view (Figure 5 c) is not recommended. Moreover, due to the reasons adduced in the previous paragraph, setting the sampling rate is not needed anyway because the user has to actively connect the SensorCard to the smartphone anytime they want to read data.

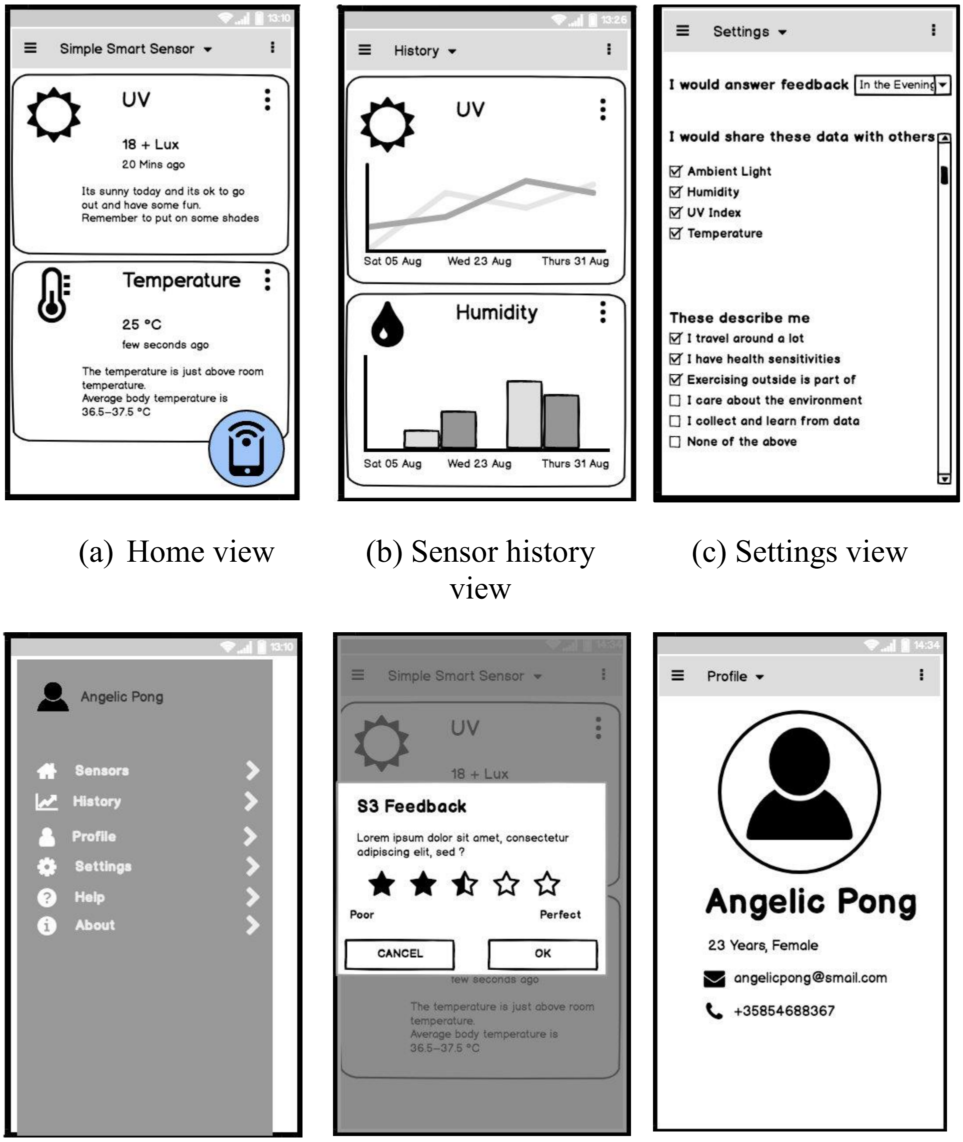
Third, the UI sketches in Figure 5 places the navigation at the bottom, in addition to navigation drawer showed with the three lines at the top left corner of each UI sketch. From a user's perspective, using the two navigation styles adds a level of complexity to the application. The navigation drawer style is prefered since it is easy to extend the number of items in the menu.

Finally, the application could determine and read data for only available sensors on the SensorCard. The list of sensors to sense data from should not be configurable by the user as shown in Figure 5 c.

3.1.3.3. User Interface Mockups

Following the expert review, UI mockups were designed from the UI sketches, taking into consideration the feedback from the expert evaluation. Figure 6 a to d, shows the UI mockups. A scan button with a sensing icon was introduced on the Home view in order to make it easier for users to collect data, even though just by tapping the smartphone with the SensorCard is an alternative way of collecting data from the SensorCard. The UI sketches were designed using the Balsamiq mockup[10] tool.

[10] https://balsamiq.com/products/



(a) Home view (b) Sensor history view (c) Settings view

(d) Menu view (e) Feedback view (d) User profile view

Figure 6. User interface mockups of S3 application.

3.1.4. Implementation and Architecture

The S3 application was developed as an Android application using the Java programming language and Android Studio IDE, taking into consideration the feedback from the user study. The application follows a Model View Presenter (MVP) architecture in organising its classes and functionalities. In the MVP architecture, the Model is responsible for managing the data which includes create, read, write and update of data, and provides interfaces for communicating with other components of the application. The View translates the data into things we see on the application interface, and the Presenter responsible for the communication between the View and the Model. The Presenter queries the model and updates the View accordingly, based on a defined logic. Table 2 shows the organisation of the various classes and functionalities in the code from the root of the package folder.

Table 2: Organisation of S3 application classes and functionalities

Folder	File	Description of content
Model	AmbientLightData.java	Object representation for the Ambient Light, Humidity, Temperature, and UV data collected measured from the SensorCard.
	HumidityData.java	
	TemperatureData.java	
	UVData.java	
	Provider.java	The class that creates a standard android content provider, responsible for the model to SQLite database mapping; creating the database, and querying the SQLite database on the smartphone.
	S3_Sync.java	Defines an AWARE Data Sync background service responsible for syncing local SQLite data to the server in the cloud.
	S3PreferenceManager.java	Class responsible for managing application user preferences.
	SensorDAO.java	The class that exposes functions for create, read, update and delete of sensor data using the object representation of the sensor data, abstracting the low level implementation of the Provider.java.
	SensorList.java	A register of all sensors available on the SensorCard.
View	AboutActivity.java	Classes responsible for managing the About , Help, History, MainActivity,Settings UI.
	HelpActivity.java	
	HistoryActivity.java	

	MainActivity.java	
	SettingActivity.java	
Presenter	ContextCard.java	Define the logic for querying sensor data from SQLite database and models for updating the sensor data visualisation.
	PrettyTime.java	The class that defines a model for translating date in timestamp format to a text describing a moment in time
	SensorListEntyViewHolder.java	Adaptors binding the sensor data to the card view on the home interface of the application. They are responsible for updating the View when new sensor data is collected and saved.
	SensorListViewAdaptor.java	
	SensorDataSortComparator	
	S3_ESMPresenter	Classes for creating and scheduling Automated Feedback Sampling questionnaires based on a defined condition
	DataSensingCheckObserver	

The S3 application uses the AWARE [1] framework[11] library to sync the sensor data stored in the smartphone's local SQLite data to the server. The S3_Sync in Table 3, above, configures a sync adaptor using AWARE and runs as a background service to periodically (30 minutes by default) transfer data over an internet connection to the server. This service works in the background even when the S3 application is closed. In view of this, the AWARE also monitors the battery strength of the smartphone running S3 application and notifies users to charge the battery at 15% of battery life.

[11] http://www.awareframework.com/

3.1.4.1. Application Database

The database of the S3 application was implemented in SQLite[12]. The schema of the SQLite database table that stores the sensor data is described in Table 3.

Table 3: The SQLite database schema of Sensor data table

Column Name	Data Type	Description	Characteristics
_id	INTEGER	Unique Identifier of sensor data entry	PRIMARY KEY, NOT NULL, AUTO_INCREMENT
timestamp	DOUBLE	Time in milliseconds the data was entered into the database table.	DEFAULT 0
device_id	VARCHAR	A Universally Unique Identifier (UUID) for the device on which the application runs	DEFAULT ‘’
name	TEXT	The type of sensor example temperature	NOT NULL
value	DOUBLE	The sensor value	DEFAULT 0
double_data_timestamp	DOUBLE	The time the sensor value was collected	DEFAULT 0
double_latitude	DOUBLE	The latitude of the location where the sensor value was collected	DEFAULT 0
double_longitude	DOUBLE	The longitude of the location where the sensor value was collected	DEFAULT 0
double_loc_accuracy	DOUBLE	The accuracy of the location data	DEFAULT 0
double_loc_altitude	DOUBLE	The altitude of the location data	DEFAULT 0

As seen from Table 3 above, the sensor data is tagged with the GPS coordinates of the location where the data was sensed and the time of the data sensing(timestamp).

[12] https://www.sqlite.org/about.html

The device_id is generated (afresh) when the application is re-installed. The AWARE framework creates a similar database schema on the server to receive the incoming sensor data from the S3 application.

3.1.4.2. The Main Activity

The main activity of the application is the home screen and lists the most recent sensor readings of each sensor, stored in the application's SQLite database. Each sensor value is shown using a card. As seen in Figure 7, each sensor value card, shows an icon, the name of the sensed data, the data value, time of measurement as a moment in time, and a more button.

To read new data from the SensorCard, the user taps the smartphone' back or smartphone NFC antenna on the SensorCard, and optionally click on the Scan button. The new values are saved in the local SQLite database and the UI cards are updated accordingly.

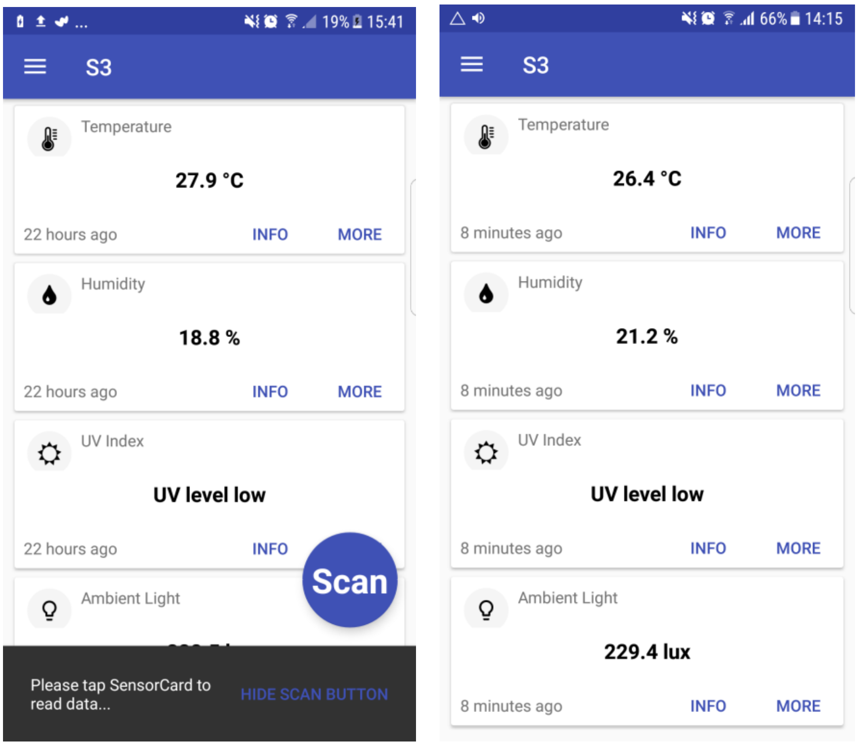


Figure 7. Main Activity of the S3 application.

The change to be noted when Figure 6 (Home view UI mockup) and Figure 7 are compared, is that the descriptive text was removed, however, clicking on the Info button on each sensor value card shows the descriptive text in a popup. The scan button icon was changed to text, and there is an option provided to hide the scan button, for users who would readily know how to read data from the SensorCard. These changes were borne out of the feedback received during the user study.

3.1.4.3. Sensor Data Visualisation

By clicking the more button on each card on the main activity, or by going to the history menu, a visualisation of the sensor data is presented to the user. The visualisation was created using the MPAndroidChart[13] library. From Figure 8, each sensor data is visualised on a card with an interactive chart that allows zoom in, zoom out, swipe left, and swipe right.

The temperature sensor data is visualised using a time series plot with the y-axis representing the temperature in degree Celsius, likewise the humidity sensor data with a time series plot with the y-axis listing the humidity in percentage. The UV index sensor data is shown with a pie chart, and Ambient Light sensor data is plotted in bobble chart where the size of the bobble correlates positively with the value of the Ambient Light in Lux.

Figure 8. Visualisation of sensor data in S3 application.

13 https://github.com/PhilJay/MPAndroidChart

3.1.4.4. Settings and About Activity

The Settings activity basically allows users to define user preferences, for example, when they are able to give feedback, and their concerns that would allow the application to adapt to the need in the future. Figure 9 shows the screens of the Settings and About activities. These two activities can be launched when the user clicks on their respective menus in the application Menu located at the top left corner of the home activity.

Comparing the Settings activity in Figure 9 below, and Figure 6 c (Settings UI mockups), the settings on data sharing has been completely remove because the application has been developed not to collect any personally identifiable data from users. Moreover to provide better services for users in the future, through machine learning, the more data the better. Also what was known as *Profile* in Figure 6 c (Settings UI mockups) has been revised to be called *Concerns* and some options that were not very related to the application, as per feedback from the user study were removed. The Setting activity also has an option to show or hide the Scan button on the Main activity as mentioned earlier.

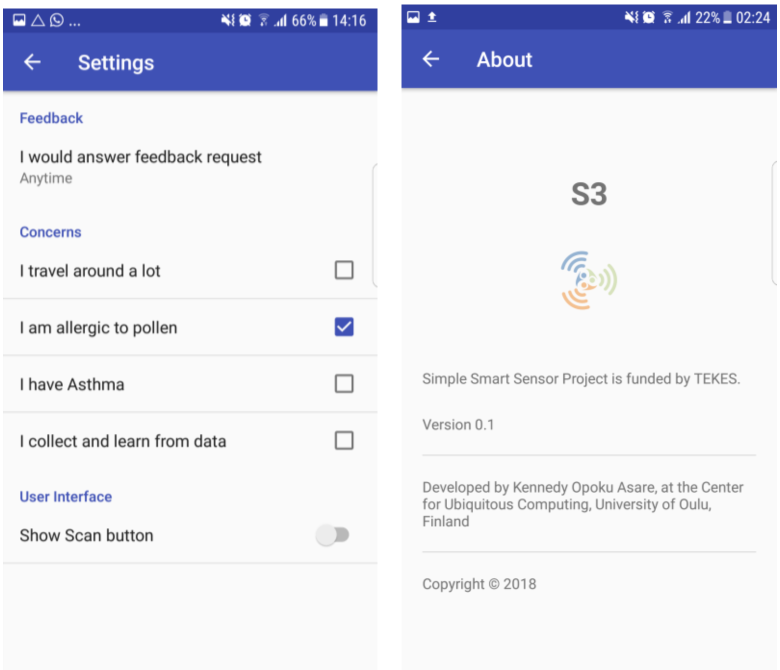


Figure 9. Screenshot of setting activity (left) and About activity (right).

The About activity also presents copyright, version, and developer information of the S3 application.

3.1.4.5. Help Activity

The Help activity, with screen shots in Figure 10, presents a simplified text-based guide for users, particularly on how to read data from the SensorCard. This activity was absent in the original design of the application, but was added owing to feedback from the user study. The Help activity launches on first time run of the application on a smartphone, and can also be launched by clicking on Help menu.

Users proceed through the guide by clicking in the Next button and finally on the Got it button, or just by swiping the screen left or right. User can also skip the guide by clicking in the skip.

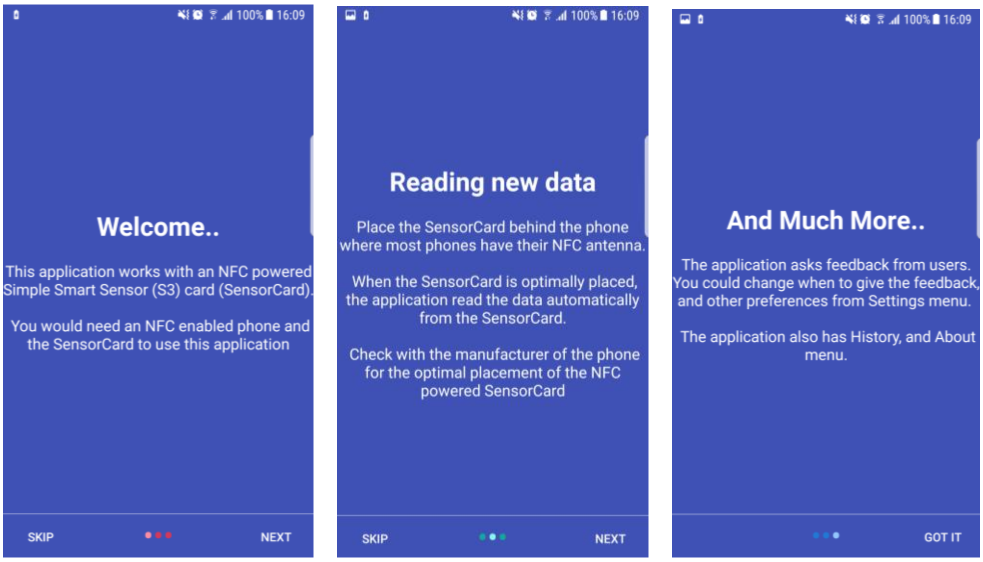


Figure 10. Interfaces of Help Activity showing a user guide

3.1.4.6. Automated Feedback Sampling

The S3 application also has an automated feedback sampling questionnaires incorporated, to collect feedback from users. This automated feedback sampling is made possible with AWARE framework's Experience Sampling Method features. These automated feedback sampling questionnaires are shown to the user, depending on a defined condition, for example, when user measures data for a defined number of times, on a context; for example when the application is installed for the first time or when the user restarts the smartphone, or randomly and at defined times within a day. Figure 11 presents screenshots of the automated feedback sampling questionnaire. The questionnaire first shows a notification, and then pops up a form after the user clicks the notification. The questionnaire can also be dynamically deployed to the user's smartphone from the AWARE dashboard.

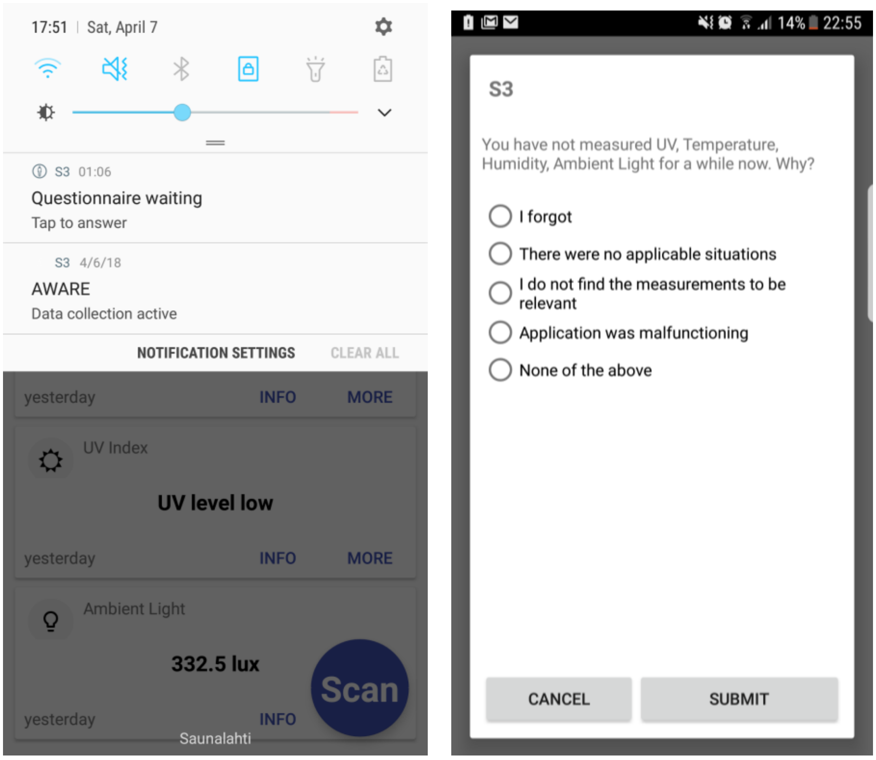


Figure 11. Automated feedback sampling questionnaire screenshots

3.2. S3 Data Server

The server of the S3 application is an AWARE dashboard. The data collected on all devices are synced into a MySQL database hosted on the AWARE framework server. The AWARE framework server then essentially becomes a data repository which provides access through MySQL login credentials available on the dashboard. The AWARE dashboard can be configured and hosted[14] on other cloud storages other than the AWARE framework server, for instance, Google cloud[15], App Engine[16], Microsoft Azure[17], and Amazon Web Services[18].

Furthermore, system configurations such as how frequent the S3 application sync data to the AWARE server, and when to clear old sensor data on user device local database can be configured from the AWARE dashboard. The new configurations are downloaded unto the devices running S3 application, the next time they connect to the AWARE server.

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[14] http://www.awareframework.com/hosting-your-own-aware-dashboard/
[15] https://cloud.google.com/
[16] https://cloud.google.com/appengine/
[17] https://azure.microsoft.com/en-us/
[18] https://aws.amazon.com/

4. RESULTS

4.1. Prototype Evaluation

To evaluate the paper prototype i.e. the printed version of the UI mockups, a user study was conducted with 30 participants, 20 males, 10 females, with their ages ranging between 20 to 32 years (mean=25.97, SD=2.85). The study participants were recruited using a campus mailing list and labelled P1, P2, P3 to P30. The purpose of the study was to find out the usability of the proposed S3 application, what features participants find useful and what features could be added or improved, and whether the application presents understandable and easy to interpret information. The outcome of the study provided useful data for the improvement of the usability and features of the application.

First, participants were briefed about the project, the project purpose and made to sign a consent form. Afterwards, two user stories or scenarios of the use of S3 application were then read to the participants.

Second, using the paper prototype, the participants were asked to perform the following five tasks;

1. Use S3 to collect a snapshot of data because you worry that UV may be too high and you want to know if you need to use sunscreen or not.
2. Check the room temperature.
3. Check if there is a change of moisture in the room.
4. Change the data you share with others.
5. Change when you are willing to provide feedback if requested.

Third, participants then rated the prototype using a System Usability Scale (SUS) questionnaire. The SUS questionnaire, is scaled from one to five with one representing *strongly disagree* and five representing *strongly agree*. The SUS questionnaire is as follows;

1. I think that I would like to use this system frequently.
2. I found the system unnecessarily complex.
3. I thought the system was easy to use.
4. I think that I would need the support of a technical person to be able to use this system.
5. I found the various functions in this system were well integrated.
6. I thought there was too much inconsistency in this system.
7. I would imagine that most people would learn to use this system very quickly.
8. I found the system very cumbersome to use.
9. I felt very confident using the system.

10. I needed to learn a lot of things before I could get going with this system.

Finally, participants were asked to provide additional feedback using the following open ended questionnaire;

1. How was the information about temperature/UV/Humidity presented?
2. Did you find any part of the application difficult to understand?
3. Where would you use the application?
4. Do you have any feature suggestions for the application?
5. Have you used a similar application before?
6. Gender
7. Age
8. Your Occupation

Each participant used an average of twenty-five (25) minutes to complete the study.

4.1.1. Quantitative Analyses and SUS Score

After the user study, analyses of the SUS questionnaire responses from participants resulted in an SUS score of 84.50, in a scale of 0 to 100, which indicates that participants were satisfied with the S3 prototype in terms of learnability and usability. Figure 12 shows a visualisation of the SUS responses.

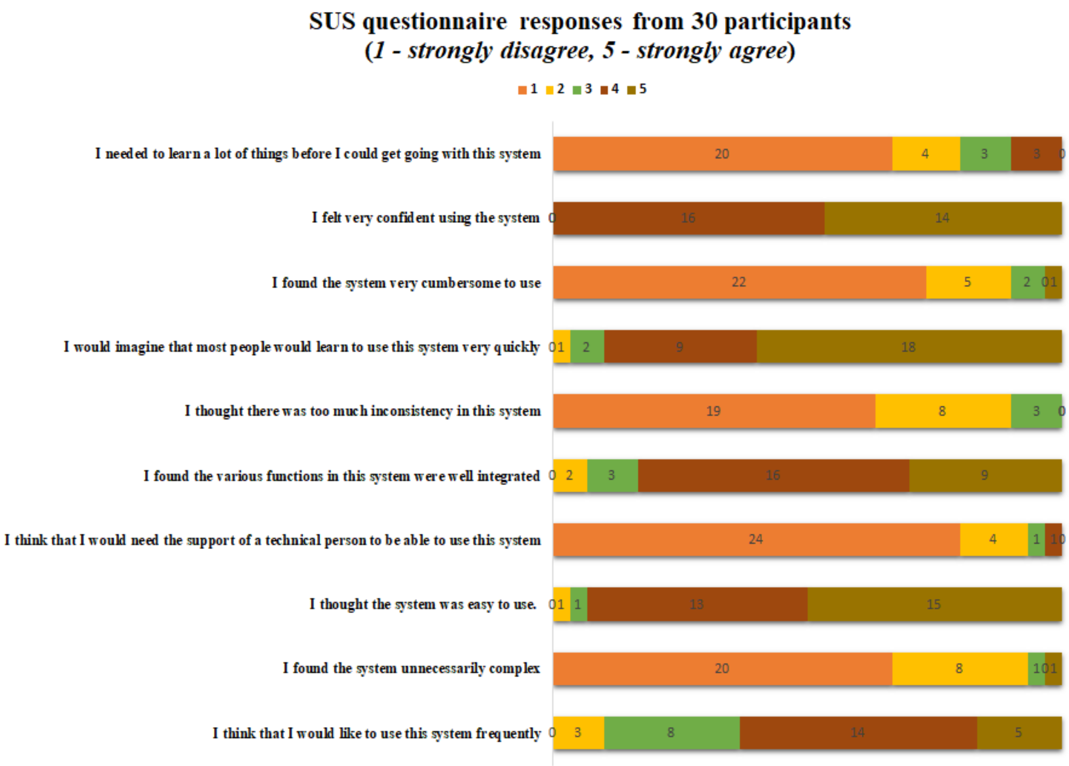

Figure 12. Visualisation of SUS questionnaire responses from 30 participants.

Table 4, below, indicates the mean and standard deviation (SD) of SUS questionnaire responses from the study. The Adjusted Mean is computed with the formula 5-Mean(Negatively scaled question response) to adjusts the Mean responses such that the negatively scaled questions (question 2,4,6,8, and 10) have the same high averages as the positively scaled questions (questions 1,3,5,7, and 9). The highest mean response among the negatively scaled questions was 1.63 (from question 10), indicating that some users needed explanations and learning before they could use the application. The difference in the average Adjusted Mean responses of all positively scaled questions and that of the negatively scaled questions is 0.68, giving an indication that the prototype gained more on its strength than it lost on its weakness.

Table 4: Mean responses of the SUS Questionnaire from 30 study participants

SUS Question	Responses		
	Mean	SD	Adjusted Mean
1. I think that I would like to use this system frequently.	3.70	0.88	3.70
2. I found the system unnecessarily complex.	1.47	0.85	3.53
3. I thought the system was easy to use.	4.40	0.72	4.40
4. I think that I would need the support of a technical person to be able to use this system.	1.30	0.70	3.70
5. I found the various functions in this system were well integrated.	4.07	0.83	4.07
6. I thought there was too much inconsistency in this system.	1.47	0.68	3.53
7. I would imagine that most people would learn to use this system very quickly.	4.47	0.78	4.47
8. I found the system very cumbersome to use.	1.43	0.90	3.57
9. I felt very confident using the system.	4.47	0.51	4.47
10. I needed to learn a lot of things before I could get going with this system.	1.63	1.03	3.37

4.1.2. Qualitative Analysis of User Study Data

Following the Grounded Theory [28,29] approach the Atlas.ti[19] tool was used to analyse the qualitative data collected during the user study. Quotations were generated from the transcripts of the qualitative data and coded using open coding method. Afterwards, the generated codes were categorised and semantically connected together to result in a conceptual model that presents the themes or concepts in the user study data. The analysis reviewed 3 major concepts; Perception of Use, Ease of Use, and Information Presentation. Figure 13 shows the conceptual model reviewed in the user study data.

[19] http://atlasti.com/

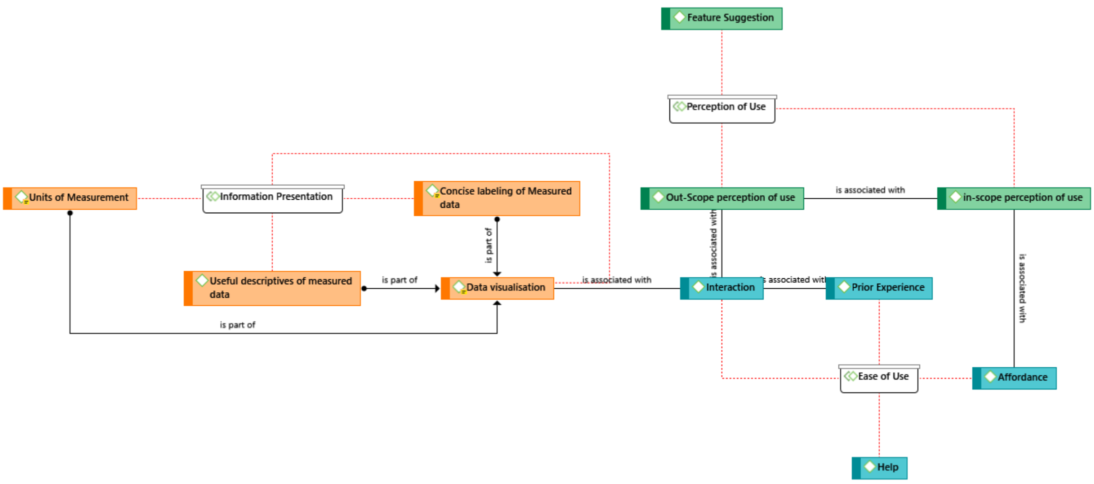

Figure 13. Conceptual model resulting from analysis of user study data.

4.1.2.1. Ease of Use

Participants' feedback on aspects of the ease of use were influenced by the affordance of UI components, and prior experience of participants with similar applications. It was observed during the study that some participants did not readily identify the use of the scan button on the interface. Depicted in Figure 14, some participant, for instance, P7 stated that "*It's not obvious how the sensors should be selected*" and also P9 commented that "*The Mobile phone with wifi-like icon isn't clear. Is it for communicating with another device via wifi or for other purpose?*". The icon on the scan button was confusing to participants and did not communicate its purpose clearly to participants. To remedy this confusion, some participants, for instance, P18 suggested: "*Auto connection with sensor card without clicking scan button*". The auto connection is possible because the NFC powered SensorCard affords an automated tap-to-read data interaction with the smartphone.

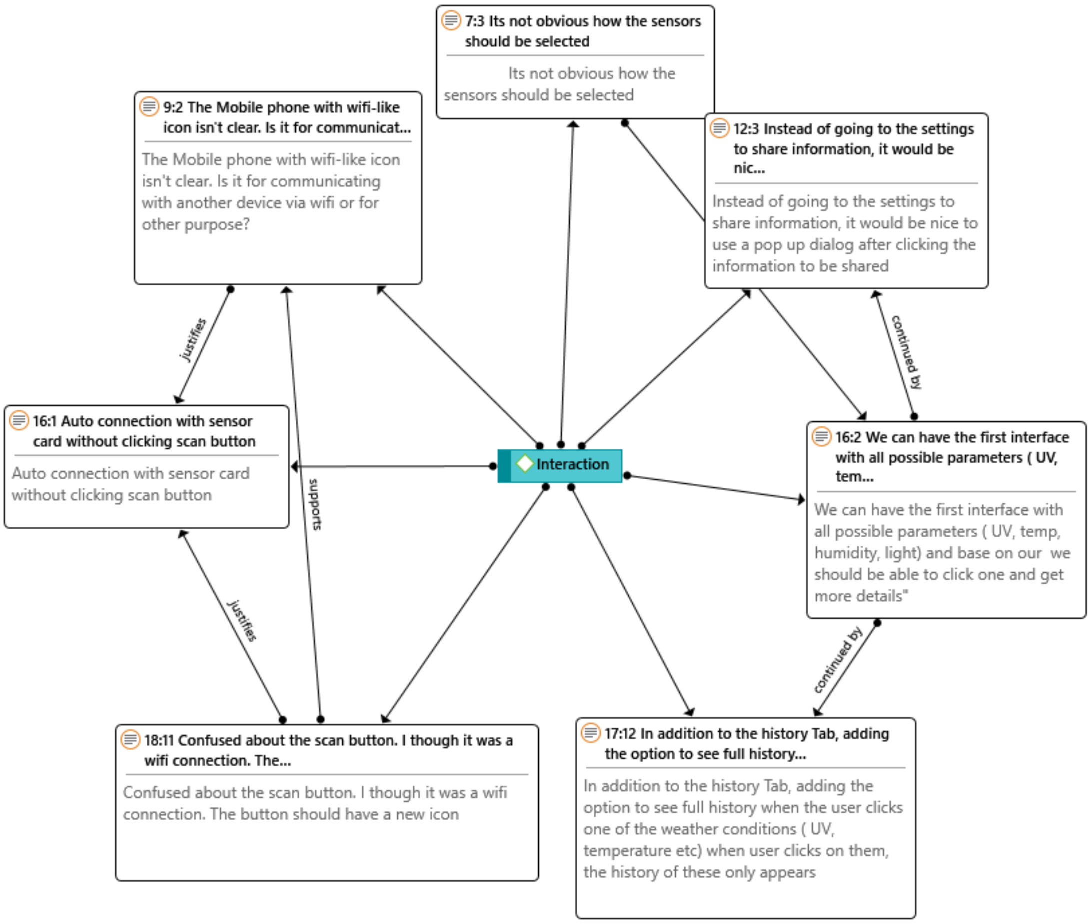

Figure 14. Participant's feedback on the Ease of use of the application.

The S3 application did not have help and introductory pages in its initial design. Some participants had prior experience with help and introductory tutorials pages available in most mobile applications, for example, weather forecast applications, and Beurer Sleep Expert[20]. These participants suggested the addition of help and introductory tutorial pages in order to improve the ease of use of the application. For instance in Figure 15, even though some participants stated that "*The design look easier and familiar to the likes of phone interfaces and its simple as well, no complications*", participants P17 suggested that "*Maybe in the actual app, add a (demo) where users are told about the NFC button. Add an Interactive tutorial*", and P6 also suggested the addition of *"Introductory tutorial on how to use the application"*.

[20] https://www.beurer.com/web/en/products/sleep-rest/sleep.php

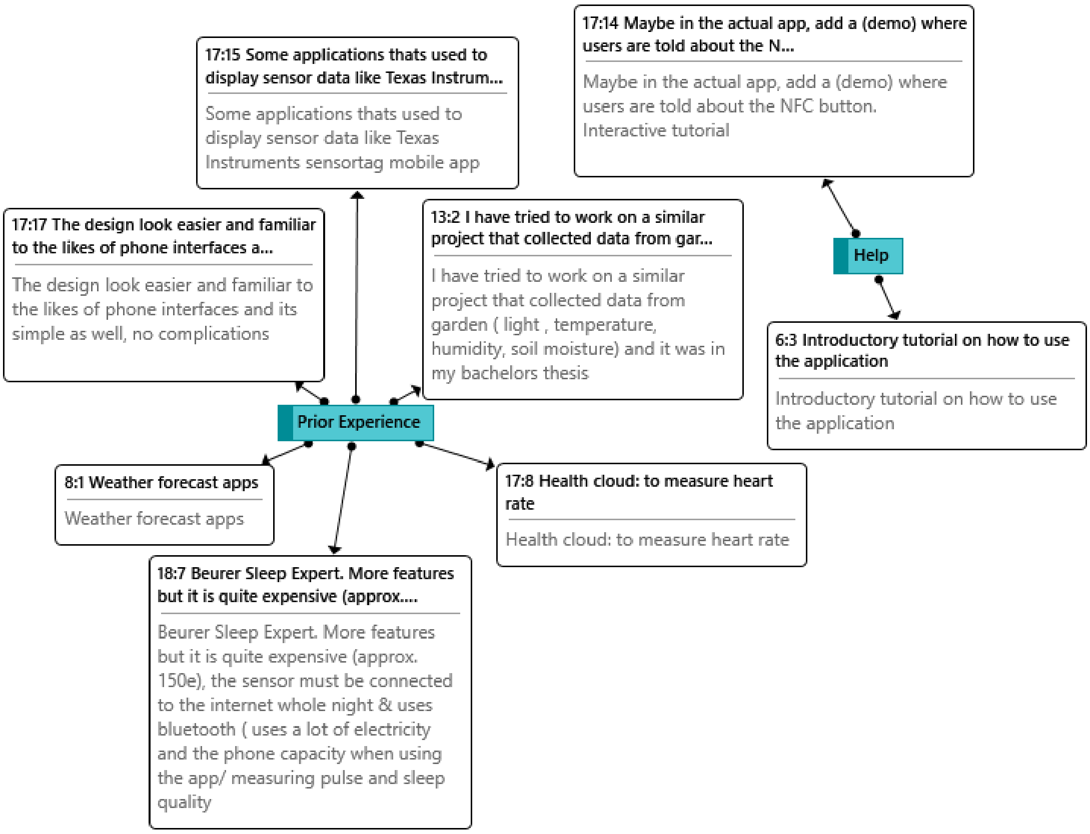

Figure 15. Some participant's feedback with regards prior experience and help.

4.1.2.2. Information Presentation

With regards information presentation in the application, the feedback was geared towards data visualisation which included; useful descriptives of measured data, clear and concise labelling of measured data and units of measurement. The home screen of the S3 application design from Figure 6 a (UI mockup of home view), provided a contextualised descriptive about the data sensor. As shown in Figure 16, below, some participants, for instance, P23 stated that "*Bigger sensor value readings since they are the main info. The paragraph text should be reduced. Let it be short and more formal. 4 or 5 words max*". P24 also said that "*The description text has nice values but would rather see it in a more visualised way than plain text*". P13 added that "*everything is well structured. Maybe the degree of temperature and UV should be bigger and the details should be displayed as optional*". P3 also said that "*The body temperature (36-37) its an extra information which user cannot use to find something useful*". These feedback sums up that, participants thought the provided descriptives of the sensor data amounts to information overloading and would want to see only the values or visualised values of the data read.

In addition, the home view (Figure 6 a) of the application prototype shows the units of measurements of the sensor data. For instance, temperature showed ºC as its units and ambient light showed Lux as its units. However, some participants could not understand these units of measurements. P1 said the app should be "*More specific about either Celsius / Fahrenheit otherwise very educational and useful*". P24 also said, "*I don't understand what Lux means*".

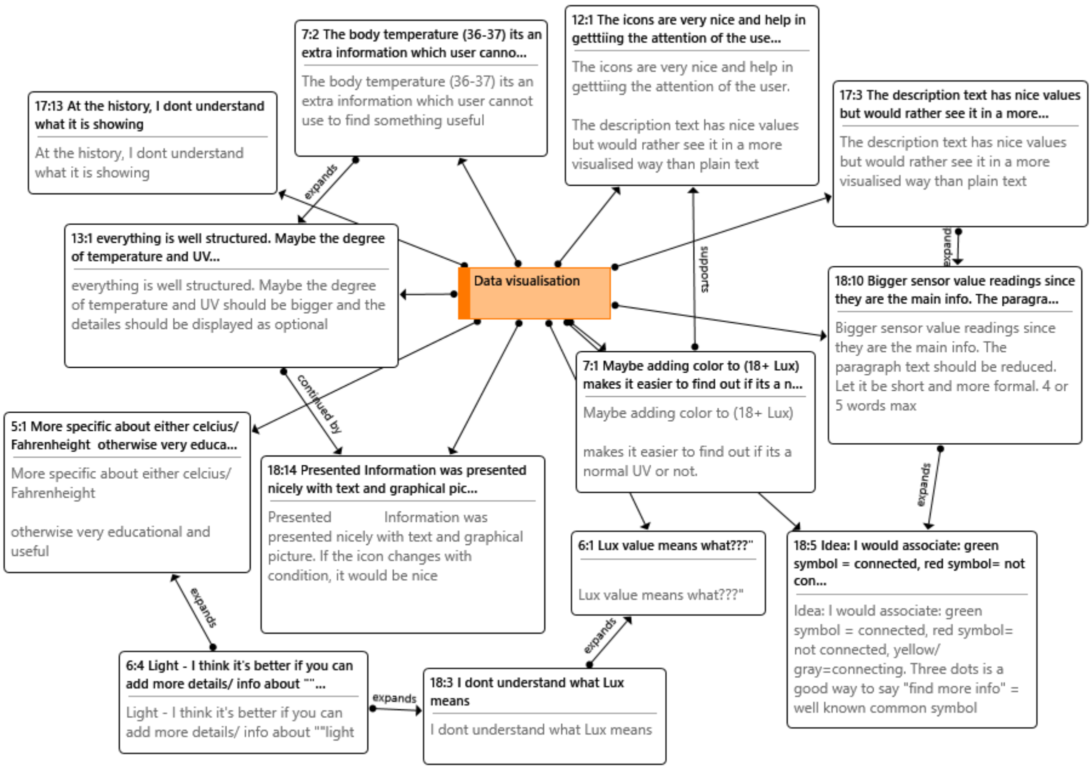

Figure 16. Feedback from participants on the information presentation.

4.1.2.3. Perception of Use and Feature Suggestions

The visual features of the prototype such as UI components, UI labeling, and the sensor data measured, influenced participants' general perception regarding the use of the application and the feature suggestions. In addition, the scenarios that were read to participants prior to the user study, also influenced participants' perception about the use of the application. The perception of use was coded into the In-scope and Out-scope perception of use. Figure 17 presents some feedback from participants in relation to the perception of use and feature suggestions.

In-scope perception of use was the perceptions of the participants about the use of the application that were already existing in the design as a functionality or could be possible to implement based on the focus and purpose of the applications. P7 stated that "*I can imagine multiple applications for that. I can collect temperature data to find out how I should set the air condition, or to know lights for different sort of rooms (living room, working room) are fine etc*". P7's perceived use case is entirely possible using the application. P21 stated that "*I would ask to add notification feature which* *will notify the user when it is a dangerous environment, or maybe a value goes beyond normal environment*". It is possible to achieve P21's suggestion upon extending the application to learn from environment fingerprint datasets, to predict which locations are likely to have for example bad air quality.

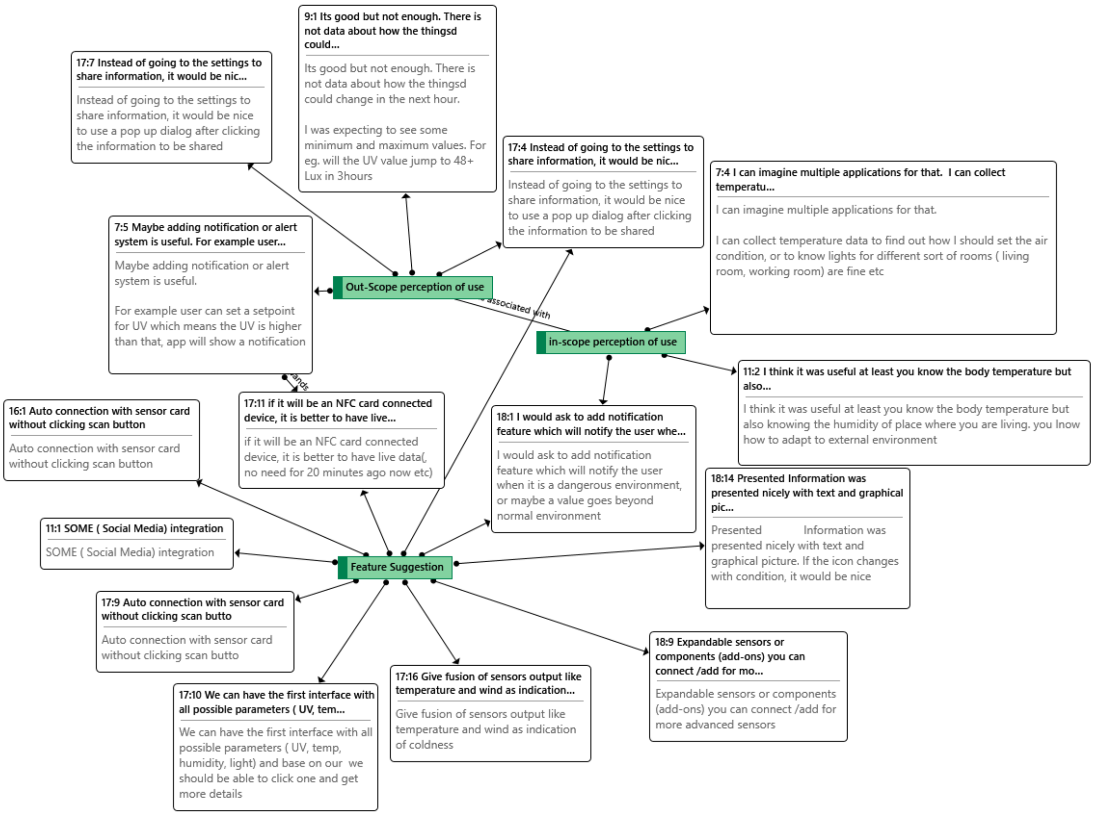

Figure 17. Perception of use and feature suggestions during the user study.

Out-Scope perception of use was the perceptions of the participants that were either non-existing as a functionality of the application, or could not be implemented due to constraints of technology such as smartphones, NFC communication and the design of the SensorCard. P9 stated that "*It's good but not enough. There is no data about how the things could change in the next hour. I was expecting to see some minimum and maximum values. For eg. will the UV value jump to 48+ Lux in 3 hours?*". UV, temperature or humidity forecasting goes beyond the scope of the application.

4.2 Test run

The outcome of the design, evaluation and implementation is that a mobile-enabled client-server system for crowdsourced environmental fingerprint datasets is created. The client, a smartphone Android application i.e. the S3 application, was designed, evaluated with 30 participants in a user study, and implemented in the Java programming language. The S3 application enables data sensing via an NFC communication from a portable SensorCard. The sensor data is visualised in the application and sync to the server. The server is an AWARE dashboard enabled online data repository.

As a demonstration of the results, the S3 application and the SensorCard was used to collect 1,576 samples of UV, Temperature, Humidity and Ambient Light data, both indoors and outdoors of the University of Oulu campus on 28th March 2018. Figure 18 shows a user tapping the smartphone with the SensorCard to read data.

Figure 18. User sensing data from SensorCard using S3 application

The data collected was exported from the AWARE dashboard and plotted into a stacked time series chart in Figure 19. The section of Figure 19 labeled A is the outdoor data sample collected at dawn around 3 am where the ambient temperature was in the negative degrees, with higher humidity, and lower ambient light. Also, the section labeled B in Figure 19 show data collected in the morning around 9 am with similar temperature and humidity as section A, but higher ambient light.

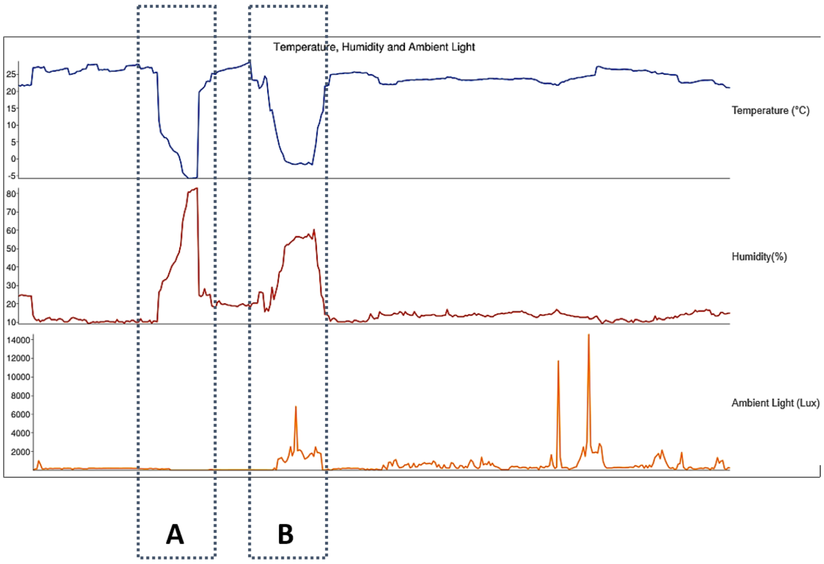

Figure 19. A plot of Temperature, Humidity and Ambient Light sensor data.

Since the sensor data are tagged with the geolocation before saving into the S3 application database, it is possible to plot a heatmap depicting environmental conditions as seen in Figure 20. Figure 20 has the University of Oulu campus where the data was collected as a basemap with points plotted at the library, central station, tellus, and tietotalo area. The heatmap was drawn with the heatmapper[21] online tool.

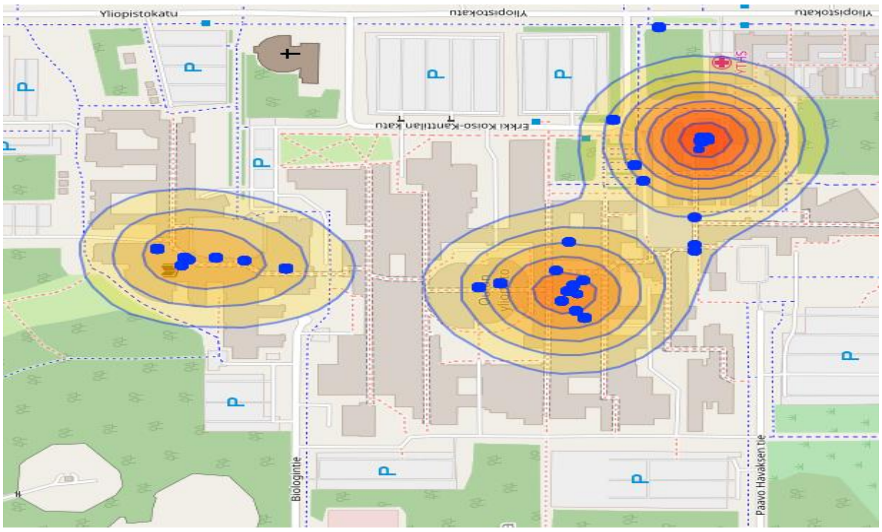

Figure 20. Heatmap of the temperature sensor data.

[21] http://www.heatmapper.ca/

5. DISCUSSION

Conventional methods of environmental fingerprinting require sophisticated and expensive infrastructure [36], besides, they are situated and can only sense the environment of their location. Using smartphones as a tool for environmental fingerprinting, however, breaks these mentioned limitations and provides the advantage of personalised environment sensing, and mobility, for a wider coverage of the environment. Smartphones, for example, android based smartphones are widely used today. Available Statistics [37,38] shows that in 2017, 1.54 billion smartphones were sold worldwide, out of which 85% used Android as their operating system. For these reasons, the developed S3 application, which is an Android smartphone based, has the potential to be used widely as a personalised solution and for research.

Current research efforts in the area of smartphone environmental fingerprinting mostly limits to a specific environmental sensor and uses Bluetooth as means of connectivity to external sensors, for instance, in Fahrni *et al.* [35], and Aram *et al.*[30]. However, using Bluetooth as connectivity to external sensors generally poses a fundamental challenge to smartphone battery life. In a survey conducted by Rahmati *et al.* [6], 80% of smartphone users turn off the Bluetooth, and GPS, when their battery levels are low. In a related survey by Ferreira *et al.* [4], smartphone users persistently kept their average daily battery low levels at 30%. Similarly in Hosio *et al.* [5], users placed three times more value on the lower levels to dying battery levels than fully charged levels. Contrary to environmental fingerprinting solutions that use Bluetooth, the S3 application senses data from the SensorCard using NFC technology. As discussed in Chapter 2 section 2.2.3. of this thesis, using NFC as connectivity significantly reduces the smartphone battery power needed to send data, and has minimal effect on the smartphone battery life. In fact, the card is powered by the smartphone itself when in contact to each other.

In comparison to the solution in Stetter *et al.* [18], which aims at providing a cheaper and personalised air quality sensor, the solution in this thesis, similarly senses and visualises data from a credit card-sized NFC powered sensor board. Furthermore, the sensor board used in this thesis has multiple sensors; UV, Temperature, Ambient Light, Humidity, rather than a single sensor as in Stetter *et al.* [18]. The S3 application further adds timestamp and geolocation context to the data and syncs the data to an online repository. The data once saved online can be analysed and visualised using the AWARE Dashboard or exported for further use.

In addition to the above mentioned features of the S3 application, a more novel feature is the inbuilt automated feedback sampling method. This feature allows researchers to dynamically define questionnaires from the server interface i.e. the AWARE dashboard. These questionnaires can then be scheduled for data collection, thus enriching data collection for research in the area of environmental fingerprint.

One identified limitation posed by using NFC connectivity on the S3 application is that users have to actively sense the data from the SensorCard by tapping the card with the smartphone and hence the S3 application is not perfectly suitable for unobtrusive data sensing. Users may simply forget to use the application. In order to mitigate this, the application schedules automated feedbacks questionnaire to enquire from users the reason contributing to the non-usage of the application.

Now for future work, the S3 application currently visualises the sensor data but provides limited insights from the data to users. Similar to the solution in Zhang *et al.* [33] a machine learning model could be used to learn from the sensor data, at the server side to provide further insight to users.

6. CONCLUSION

This thesis aimed at contributing to research in the area of Environmental Fingerprinting, by developing a mobile-enabled client-server architecture for crowdsourced environmental fingerprint datasets. The smartphone was chosen as the tool for data collection and visualisation, owing to the opportunities it avails for personal environment sensing solutions and for research. The thesis highlighted the advantages of using NFC over Bluetooth as connectivity to external sensors, as well as previous research in the area of environmental sensing with smartphones.

Following a scenario-driven approach, a smartphone application was designed and evaluated with 30 participants in a user study. The analyses of the quantitative user study data resulted in an SUS score of 84.50, implying a high usability and learnability of the designed application. The qualitative user study data was also analysed using the grounded theory approach to structure the complex user feedback into a much clearer story of user expectations and needs.

The scenarios, use cases and results from the user study contributed to the implementation of an Android smartphone client application that senses and visualise environmental data from an external zero power portable NFC sensor board. The client application, in addition, syncs data to an online data repository on the server. The server also provides tools for data visualization, data export and remote application configuration features.

Following the implementation, a test run was done to demonstrate capabilities of the developed solution, and the opportunities it lends to personal use and research in environmental fingerprinting. However, there is a need for further studies in calibrating the sensors and providing richer insights into the sensor data for users.

7. REFERENCES

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8. APPENDICES

Appendix 1 Call for User study participation email
Appendix 2 The User study guide

Appendix 1: Call for User study participation email

Subject: Looking for study participants to test and evaluate S3 - Simple Smart Sensor Application prototype.

We are researchers from the Center for Ubiquitous Computing and are looking for participants to test and evaluate our prototype application for S3 - Simple Smart Sensor Application prototype.

Would you wish to know more about your environments, and how it affects your personal health? Are you looking for the opportunity to collect data about your environment for research purposes, as well for yourself? Our application allows you to measure UV light, air humidity, water quality, and air quality.

You are given the opportunity to test a prototype S3 - Simple Smart Sensor application plus we will give you **1** coffee voucher, and 1 movie ticket later if you also test the developed S3 application.

Please reply to me (kennedy.opokuasare@oulu.fi) if you are interested, and please forward this message to anyone who you might think would be interested. More details on the study itself are as follows:

Project name:
S3 - Simple Smart Sensors Application

Goal of study:
To evaluate and improve the prototype of the S3 application, to inform the implementation of the application

How long would it take?
The study takes approximately 45-60 minutes

What data would be collected?
The study does not collect any private data (name, address, contact information or other personal identifiers). The study only collects your input on the presentation of Information, level of difficulty of use of a proposed S3 application, possible feature suggestions, age, gender, and occupation and your views about the usability of the proposed application using a 1-5 scale set of questions.

Please reply to this email to confirm your interest to participate. We plan to start the study from 12th December to 22nd December 2017.

Thank you.

Kennedy Opoku Asare

Appendix 2: The User study guide

S3 - Simple Smart Sensors Application

User Interface Design Evaluation Guide

Researcher: Kennedy Opoku Asare (kennedy.opokuasare@oulu.fi)

Participant ID: ______________________

Date: ______________________

Consent form

Purpose of study

The participant is asked to evaluate a paper prototype of S3 android application yet to be implemented. The study would try to find out the usability of the proposed S3 android application, its usefulness to participants, what features participants finds useful and what features participants think could be added or improved, whether it presents understandable and easy to interpret information. The outcome of the study would provide useful data for the improvement of the usability and feature of the proposed S3 android application.

Collected Data

This study collects data on the following;

- Presentation of Information, level of difficulty of use of proposed S3 application
- Possible feature to be added, changed or improved, experience with similar applications.
- Age, gender, and occupation of participants
- 1-5 scale response from participant using System Usability Scale (SUS)

Procedures

This study would table approximately 45 - 60 minutes to complete.

Upon meeting participant;

- The participant would be introduced to the purpose of the study, data collected, compensation, confidentiality of the study, after which participant would be asked to sign the consent form.
- The participant would be introduced one use case story or scenario

The participant would then be asked to perform the following tasks using the paper prototype of the proposed S3 android application.

- Use S3 to collect a snapshot of data because you worry that UV may be too high and you want to know if you need to use sunscreen or not.
- Check the room temperature.
- Check if there is a change of moisture in the room.
- Change the data you share with others.
- Change when you are willing to provide data if requested.

After the above tasks are performed, a semi-structured questionnaire would be administered to the participant for responses. The participant would then be handed with a compensation.

Compensation

The participant would be rewarded with 1 coffee voucher after performing the tasks and completing the semi-structured questionnaire. Participants who agree to be retained for evaluating the S3 application after it has been developed would receive a movie ticket when they testing of the developed application is done.

Participants' requirement
Communication during the study would be in English, and as such, the participant is required to be able to communicate in basic English. No previous knowledge of the use of similar applications to S3 is required. Since S3 is currently a paper prototype, we have no requirements for participants to own an android mobile phone.

Risks
The risk associated with the participation of this study is no greater than ordinary sitting and communicating with a third party for some few minutes less than an hour.

Benefits
There would be no personal benefits to the participants, however, the knowledge gathered from the participation will be valuable to research.

Confidentiality
Your data and consent form will be kept separate. Your consent form will be stored in a locked location at the University of Oulu and will not be disclosed to third parties. By participating, you understand and agree that the data and information gathered during the study may be used by the University of Oulu and published and/or disclosed by the University of Oulu to others outside the University of Oulu for further analysis. However, no private data (name, address, contact information or other personal identifiers) in your consent form will be mentioned in any of such publication or dissemination of the research data and/or results by the University of Oulu.

The researchers will take the following steps to protect participants' identities: each participant is assigned a number; the data is collected during the study by the number, NOT the name; any data will be stored indefinitely in a secure and password protected location accessed only by authorized researchers.

By signing this document, you are formally agreeing to collect the previous described data and you have been answered all the questions you might have had about this document and the study by the researcher in this room.

________________________________ (date and your signature)

User Interface Design Evaluation Questionnaire

Participant ID: ______________________

Date: ______________________

How was the information about temperature/UV/Humidity presented?

____

____

____

Did you find any part of the application difficult to understand?

____

____

____

Where would you use the application?

____

____

____

Do you have any feature suggestions for the application?

____

____

____

Have you used a similar application before?

____

____

____

You are:

Gender_______ Age: ______

Your Occupation: ___________________________________

Mark the following boxes labeled 1 to 5 for each question based on your assessment of the application.

	Strongly disagree				Strongly agree
1. I think that I would like to use this system frequently.	1	2	3	4	5
2. I found the system unnecessarily complex.	1	2	3	4	5
3. I thought the system was easy to use.	1	2	3	4	5
4. I think that I would need the support of a technical person to be able to use this system.	1	2	3	4	5
5. I found the various functions in this system were well integrated.	1	2	3	4	5
6. I thought there was too much inconsistency in this system.	1	2	3	4	5
7. I would imagine that most people would learn to use this system very quickly.	1	2	3	4	5
8. I found the system very cumbersome to use.	1	2	3	4	5
9. I felt very confident using the system.	1	2	3	4	5
10. I needed to learn a lot of things before I could get going with this system.	1	2	3	4	5

Thank you for your time